CALIFORNIA
ENERGY
COMMISSION

Landfill Gas-To-Energy Potential In California

STAFF REPORT

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Legal Notice

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliability energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), has annually awarded up to $62 million through the year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Residential and non-residential buildings end-use energy efficiency
- Industrial, agricultural, and water end-use energy efficiency
- Renewable energy technologies
- Environmentally preferred advanced generation
- Energy-related environmental research
- Strategic energy research

In 1998, the Commission awarded approximately $17 million to 39 separate "transition" RD&D projects covering the 5 PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

For more information on the PIER Program, please visit the Energy Commission's website [http://www.energy.ca.gov/pier/reports.html] or contact the Commission at (916) 654-4628.

Executive Summary

California leads the nation in solid waste production. In 1990, Californians generated approximately 51 million tons of waste and disposed of approximately 42 million tons. Now, California diverts more than 42 percent of its waste, resulting in disposal of approximately 38 million tons per year. In California today, a total of 311 landfills are active with 51 landfill gas to energy (LFGTE) projects in the state. In this report, the landfill gas to energy projects are separated into landfill gas to electricity projects, landfill gas to heat projects, and landfill gas to pipeline gas projects.

The total electrical generation capacity from the existing landfill gas to electricity projects in California is about 211 MW_e. In addition, 26 landfills have planned to install landfill gas to energy facilities. The electrical potential from the planned 26 landfills is about 39 MW_e. In California today, 70 landfills are flaring the landfill gas they are producing. These 70 landfills have the potential for producing approximately 66 MW_e of electricity. Also 164 landfills either do not have landfill gas control systems or are venting the landfill gas to the atmosphere. These 164 landfills have the potential for producing approximately 31 MW_e of electricity. Additionally, some of the existing LFGTE projects are operating below their rated electricity generation capacity. About 45 MW_e of electrical potential could be added by expanding existing landfill gas to energy projects in California.

Gas turbines, boilers, steam turbines, combined cycles, and reciprocating engine are the technologies that are used to convert landfill gas into electricity in California. For gas turbines and steam turbines in California, the combined capital cost for electrical generation and gas collection facilities averages about $3500 per kWe generated. Most of the landfill gas to electricity projects use reciprocating engines. The capital costs of combined electrical generation and gas collection facilities using reciprocating engines range from $606 to $6811 in California.

The trends for landfill gas to energy project costs in California similar to those in the U.S.. In California, reciprocating engines appear to be the best currently available option (pending further commercialization of microturbines and fuel cells) for facilities up to approximately 10 MW_e in size, and this trend appears to hold true for the rest of the U.S.. The use of reciprocating engines in this large number of facilities is based on economic information only; consequently, when other factors such as emissions are taken into account, other technologies become better options. When looking at facilities sized from around 10 MW_e up to approximately 18 MW_e the data favor the use of gas turbines. In facilities larger than 18 MW_e steam cycles, gas/steam combined cycles appear to be the best investment.

I.0 INTRODUCTORY DISCUSSION ON SOLID WASTE GENERATION AND LANDFILLS IN CALIFORNIA

California leads the nation in solid waste production. Currently, California diverts more than 42 percent of its waste, resulting in disposal of approximately 38 million tons per year.[1] Figure 1 shows the solid wastes landfilled in California from 1990 to 2000.[1] In 1990, Californians generated approximately 50.9 million tons of waste and disposed of approximately 42.4 million tons. Currently, 311 landfills remain active, from a totoal of over 3000 landfills in California. The locations of total and active landfills in California are included in map 1.

2.0 SOLID WASTE GENERATION IN CALIFORNIA

2.1 Solid Waste Generation in California by Sectors

The California Integrated Waste Management Board (CIWMB) commissioned a Statewide Waste Disposal Characterization Study to obtain data to characterize the waste streams in California. The waste steams are divided into three sectors: residential, commercial, and self-haul as descripted in Table 1.[2]

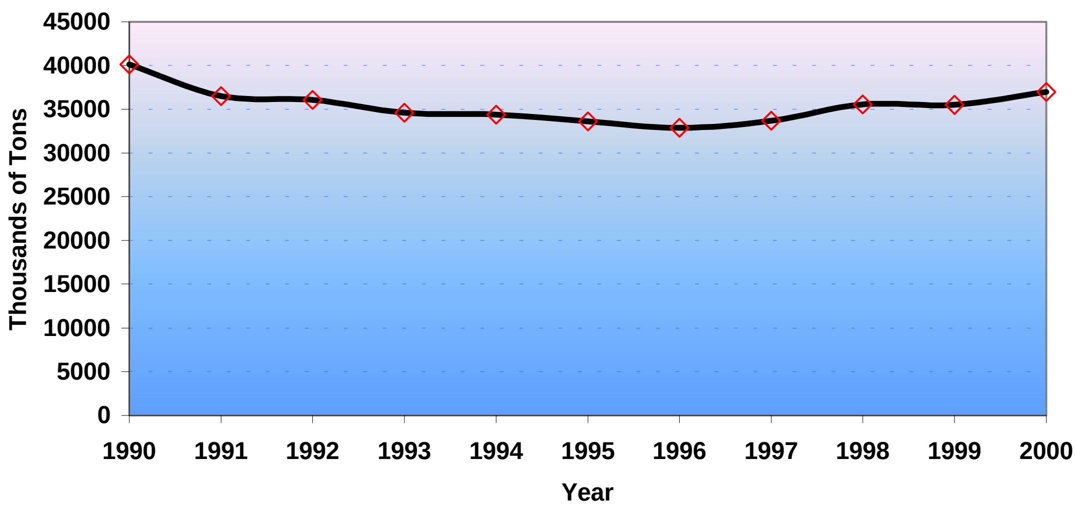

Figure 1. California's Landfilled Solid Waste Stream (1990-2000)

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[1] California Integrated Waste Management Board. 2001. www.ciwmb.ca.gov
[2] Statewide Waste Characterization Study, December 1999. California Integrated Waste Management Board.

Table 1. Descriptions of Waste Disposal Sectors in California

Sectors	Descriptions
Commercial Wastes	Waste disposed by businesses, industries, and public organizations that is collected and transported by professional waste haulers, including waste disposed by specific industry groups based on SIC codes.
Residential Waste	Waste disposed by households that is collected and transported by professional waste haulers, including wastes that are collected from single-family residences and from apartments or condominiums.
Self-Haul Waste	Waste that is transported to the disposal site by someone whose primary business is NOT waste hauling, including waste hauled to a disposal site by a resident from their home and waste hauled to a disposal site by a commercial enterprise (e.g. landscaper, contractor, etc.

In 1998, over 35 million tons of solid wastes were disposed through landfill, in which the commercial sector comprised 48.8%, the residential sector 38.1%, and the self-haul sector 13.1% as shown in Table 2.[2]

Table 2. Estimated Contribution of Each Sector to the Overall Waste Stream in California

Source of Waste Stream	Est. Percent of Waste Stream	Est. Tons Statewide (1998)
Commercial	**49%**	**17,358,359**
Residential	**38%**	**13,525,627**
Single-family residential	28%	9,955,739
Multifamily residential	10%	3,569,888
Self-haul	**13%**	**4,651,466**
Commercial self-haul	10%	3,739,696
Residential self-haul	3%	911,770
Totals	**100%**	**35,535,452**

2.2 Amount of Waste Materials Entering California Landfills by Type

The types of wastes entering California landfills vary by waste generation sectors. Table 3 summarizes the different types of waste in commercial, residential, and self-haul waste generation sectors. Of the total solid wastes generated in California in 1998, the organic portion including paper and other organics was 65% or over 23 million tons.

Table 3. Amount of waste materials entering California landfills by type in 1998

Material Type	Commercial	Residential	Self-haul	Total	Est. Total Tons (1998)
Paper	39.0%	27.4%	5.5%	30.2%	10,742,707
Glass	2.4%	4.0%	1.0%	2.8%	1,011,441
Metal	6.0%	4.6%	10.6%	6.1%	2,164,080
Plastic	9.8%	8.8%	5.6%	8.9%	3,161,711
Other Organic	31.3%	45%	20.8%	35.1%	12,490,171
Construction & Demolition	6.4%	4.5%	51.3%	11.6%	4,110,526
Household Hazard. Waste	0.3%	0.3%	0.1%	0.3%	106,497
Special Waste	4.1%	1.2%	4.9%	3.1%	1,100,383
Mixed Residue	0.5%	4.0%	0.2%	1.8%	637,938
Totals	**100%**	**100%**	**100%**	**100%**	**35,535,453**

3.0 LANDFILL GAS-TO-ENERGY (LFGTE)

3.1 Landfill Gas Generation

When a landfill is capped, the biodegradable organic portion of the solid wastes serves as the food for anaerobic bacteria under anaerobic (without oxygen) conditions. Landfill gas is generated when organic solid wastes are decomposed. Landfill gas mainly contains methane (CH_4) and carbon dioxide (CO_2). Uncontrolled landfill gas can result in a potential hazard since methane is explosive in air at concentrations between 5 and 15 percent.[3] Utilization of landfill gas using LFGTE technologies brings energy, environmental, and economic benefits in increasing electrical generation capacity, improving air quality and reducing odors, and creating jobs in the state.

The anaerobic decomposition of solid wastes in a landfill can be described as:

$$\text{Biodegradable Organic matter} \xrightarrow[\text{Bacteria}]{\text{Without } O_2} CH_4 + CO_2 + H_2S + H_2O + \text{Others}$$

[3] Landfill Methane Utilization Technology Workbook. 1981. Prepared by Jill L. Baron, Russell C. Eberhart, Linda Green Philips, Steven L. Shadel, and Gary A. Yoshioka, The Johns Hopkins University, Applied Physics Laboratory. Prepared for U.S. Department of Energy Division of Buildings and Community Systems through Argonne National Laboratory.

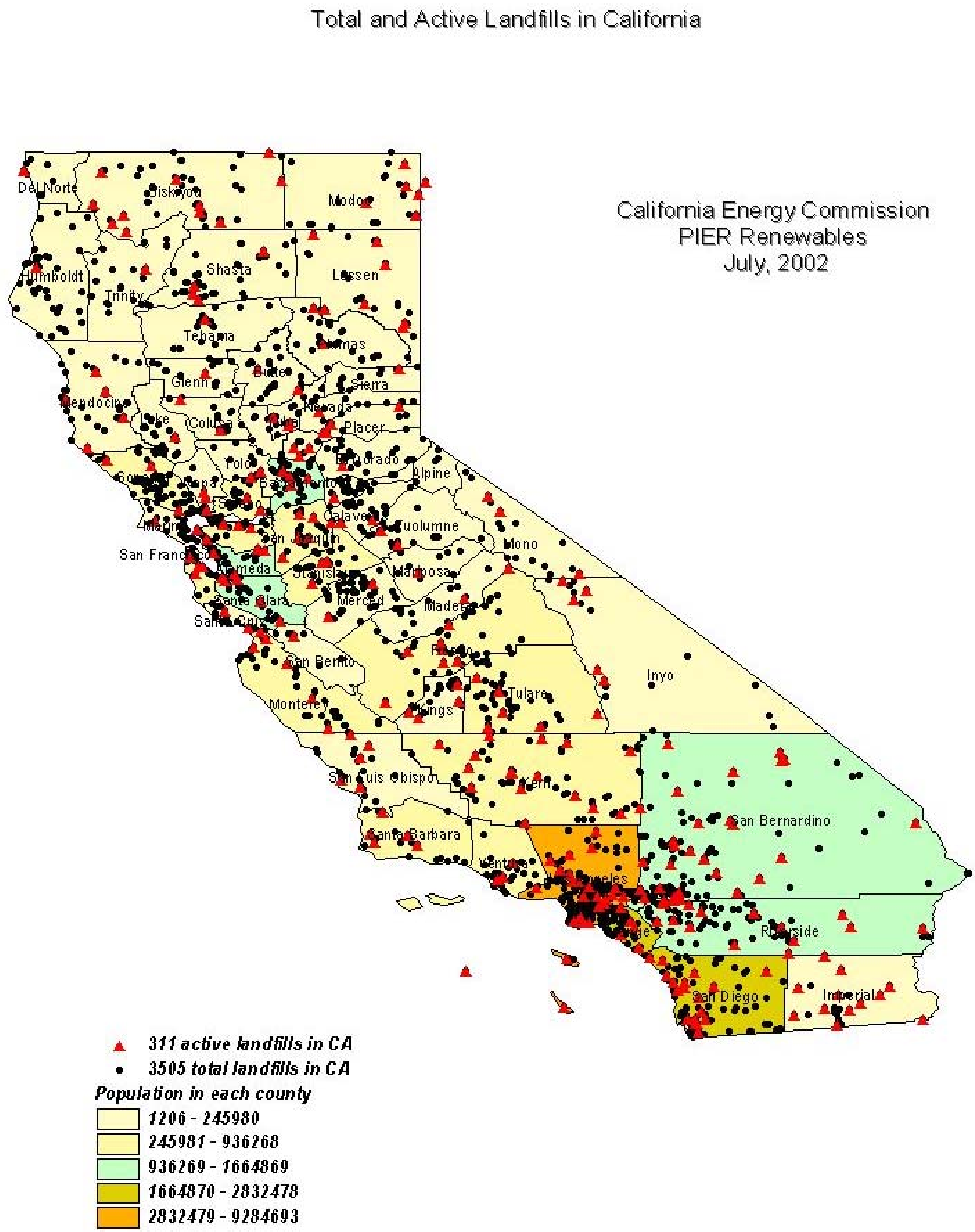
The composition of landfill gas varies from landfill to landfill depending on many factors, such as the composition of the solid waste, total moisture content, and temperature. In general, landfill gas consists of 35-60% of CH_4, 40-55% of CO_2, and other tracing gases, such as H_2S, O_2, and N_2. Table 4 shows a typical landfill gas composition.[4] H_2S, and CO_2 can dissolve in water, causing water to become acidic and thus corrosive. In the presence of O_2, H_2S and CO_2 become more corrosive. Elevated temperatures due to compression of the gas can also increase the corrosion rate.[5] Recently, Siloxane has been increasingly found in landfill gas produced at landfills. Siloxane has been a problem for engine generators and appears to pose a very significant threat to the performance of microturbines. Siloxane damages turbine blades, greatly reducing the projected useful life of the engine.

Table 4. Landfill Gas Characteristics

	Units	Range for Most U.S. Landfills	Penrose Landfill	Groton Landfill
LFG Flow Conditions				
Total LFG Produced at Site	ft^3/min	70-5000	3000	400
LFG Higher Heating Value	Btu/ft^3	349-598	446	585
Moisture	%	1-10	Dry	Wet
LFG Composition (by Volume)				
Methane	%	35-58	44	57
Carbon Dioxide	%	40-55	38	41
Nitrogen	%	0-15	17.6	1.3
Oxygen	%	0-2.5	0.4	0.41
Total Halides (as Cl)	ppmv	NA	45-65	7-45
Total Sulfur (as H_2S)	ppmv	1-700	111	182
NMOCs (as methane)	ppmv	237-14294	130-475	NA

Source: Landfill Gas Energy Utilization: Technology Options and Case Studies. 1992. Prepared by Don Augenstein, and John Pacey. Prepared for U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C. 20460.

[4] Landfill Gas Energy Utilization: Technology Options and Case Studies. 1992. Prepared by Don Augenstein, and John Pacey. Prepared for U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C. 20460.
[5] Effects of Corrosion at the Mountain View, CA, Landfill Gas Recovery Plant. 1981. Prepared by Pacific Gas and Electric Company, San Francisco, CA. Submitted to U.S. Department of Energy, Washington, D.C.



Map 1. Total and Active Landfills in California

3.2 Landfill Gas Control Systems

The movement of landfill gas in a landfill occurs by two basic processes: convection (movement in response to pressure gradient) and diffusion (movement from areas of high concentration to regions of lower concentration). Because methane is lighter than air, it tends to move vertically and escape to the atmosphere. The cover material on a landfill causes enough resistance to encourage lateral movement of the landfill gas. Migration control is necessary. Collection wells should be located around the boundary of the landfill if migration control were the only consideration. In most cases, however, the gas is routed to one or more locations to be vented, flared, or recovered for energy applications. Generally, an internal well and piping system is used to recover LFG for use in an energy application. It may be necessary to have two separate collection systems; one for migration control and another for gas recovery and utilization.[3]

3.3 Landfill Gas Extraction

One of the first steps in the construction of a new landfill gas recovery system is to drill and install extraction wells. An extraction well can be designed to permit gas recovery at selected depth intervals. The gas withdrawn at each well is collected at a central point by means of a pipe network referred to the gas collection header. A compressor unit is normally the source of the applied suction and the central point to which gas is collected, although a motor/blower unit may be suitable for certain projects. Gas recovered from a landfill is normally saturated with moisture. During collection in the header system, the gas undergoes a slight expansion and temperature decline, and some water condenses, accumulating in the low spots of the header pipe. Condensate drains should be located at all low spots and at more or less regular intervals along the gas collection header. A condensate drain basically consists of a small diameter pipe connected to the header line by a tee or saddle.[6]

3.4 Landfill Gas Treatment

Treatment is required for the landfill gas before it is utilized. Several methods are available and the end use of the gas determines the degree and method of treatment. Water can be removed by adsorption using alumina, molecular sieves, or by triethylene glycol absorption. Carbon dioxide can be removed with chemical solvents, physical solvents, a combination of two, with solid adsorbents (molecular sieves), or with membrane filters. Landfill gas may be treated specifically for the removal of other constituents, such oxygen and hydrogen sulfide.[7]

3.5 Landfill Gas Utilization Systems

The four basic options for the utilization of landfill gas are listed below. They differ in the effort required to produce the end product and in the capital and operating costs.

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[6] State of the Art of Landfill Gas Recovery. 1981. Prepared by EMCON ASSOCIATES. Prepared for Argonne National Laboratories, Pacific Gas and Electric Company, and Southern California Gas Company.
[7] Blanchet, M.J., and staff. 1977. Treatment and Utilization of landfill Gas: Mountain View Project Feasibility Study. U.S. Environmental Protection Agency report SW-583.

3.5.1 Medium British Thermal Units (Btu) Gas Use

Medium-Btu landfill gas can be used in a number of ways. Typically after condensate and particulate removal, the gas is compressed, cooled, and dehydrated. The gas then can be transported by pipeline to a nearby location for use as fuel for boilers, burners, or generation systems. Minor modifications are required to natural-gas-fired-burners when landfill gas is used because of its lower heating value and different composition (high CO_2). Another alternative is to generate steam at the landfill site. The landfill gas, after condensate and particulate removal and compression, is burned in a boiler to raise steam. The customer for this steam needs to be close to the site since high pressure steel insulated pipeline is expensive and heat is lost during transport.[3]

3.5.2 Generation of Electric Power Using Reciprocating Engines, Gas Turbines, Steam Turbines, Microturbines, And Fuel Cells

Electricity is already generated on-site using reciprocating engines, steam turbines, or gas turbines. To use LFG in reciprocating engines and gas turbines, condensate and particulates matter must be removed. To move fuel gas into a gas turbine combustion chamber, the gas must have most of the visible moisture and any particulates removed and then compressed. Using a steam turbine requires generating the steam first.[3] Microturbines can be used to generate electricity at a capacity as small as 30 kW. However, the costs of landfill gas clean up and the current limited reliability of microturbines cause economic uncertainty in application. The microturbine technology has not been fully commercialized. High cost associated with landfill gas clean up is also an important issue for application of fuel cell technology.

3.5.3 Injection into A Natural Gas Pipeline

Landfill gas can be upgraded into high-Btu gas and injected into a natural gas pipeline. As compared with other power generation alternatives, the capital cost for sale of upgraded pipeline quality gas is high because treatment systems that are used to remove CO_2 and impurities are required. Also, upgraded gas needs a significant amount of compression to conform to the pipeline pressure at the interconnection point. However, the advantage of pipeline quality gas technology is that all the gas produced can be utilized.

3.5.4 Conversion to Other Chemical Forms

It is possible to convert the landfill gas to another form such as methanol, ammonia, or urea. Of these three options, conversion to methanol is the most economically feasible. To convert high methane content gas to methanol, water vapor and carbon dioxide must be removed. In addition, the gas must be compressed under high pressure, reformed, and catalytically converted. This tends to be an expensive process, which results in about 67 percent loss of available energy.[8] Landfill gas reforming can also be used to produce hydrogen for fuel cells.

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[8] Ham, R.K., K.K. Hekimian, S.L. Katten, W. J. Lockman, R.J. Lofy, D.E. McFaddin, and E.J. Daley. 1979. Recovery, Processing, and Utilization of Gas from Sanitary Landfills. EPA-600/2-79-001.

4.0 LFGTE TECHNOLOGIES AND PROJECTS IN CALIFORNIA

4.1 Existing LFGTE Technologies in California

In California today, many different technologies are being used to convert landfill gas to electricity. The major technologies in use and currently proposed include boilers, reciprocating engines, gas turbines, and steam rankine cycles employing steam turbines.

4.1.1 Boilers

The use of landfill gas as fuel for large industrial boilers is an appealing option. In boilers, the landfill gas is combusted in a burner and the hot combustion gases are allowed to contact heat transfer elements containing water. If the industrial application can take advantage of the 24 hr nature of landfill gas supplies, or if landfill gas can be used as a supplemental fuel, many industries could benefit from cheap landfill gas. Another advantage of boiler applications is the comparatively low emissions compared to other options. The disadvantages include the continuous nature of the gas flow and the higher cost to store or transport landfill gas, which requires that industrial applications be located on or near landfill sites. The colocation of landfills and industrial plants can exacerbate already stressed air quality requirements.

4.1.2 Reciprocating Engines

Reciprocating engines are commonly used in the production of electricity. The sizes of the engines range from 51 kW to 10,000 kW. The engines used in landfill application are typically large displacement natural gas units that are converted for landfill gas use. There are three main manufacturers of these engines: Caterpillar, Cooper-Superior, and Waukesha. In recent years, there has been considerable investment in reducing the emissions from reciprocating engines; furthermore, companies have explored lean-burn fuel mixing and turbocharging of input air with varying results in reducing emissions. Despite these efforts, reciprocating engines are still orders of magnitude worse in the emission of NO_x and CO than turbines or boilers. One of the major obstacles in the use of reciprocating engines is the corrosive effect of minor components in the landfill gas; these components have necessitated the redesign of the bearings, valve seats, and oil monitoring systems. Despite the difficulties with reciprocating engines, the economic advantages of these engines continue to induce their use in many applications.

4.1.3 Gas Turbines

Gas turbines are an excellent electrical generation option where the economics can support the capital cost of the turbines. Turbines, when compared to internal combustion engines, produce very small amounts of NO_x and CO and are fairly efficient (16,000 Btu / kW-hr) in the conversion of landfill gas to electricity. The most common turbines in use at landfills in California are Solar turbines, specifically the Saturn and the larger Centaur models rated from 1-5 MW_e. In landfill applications, the standard natural gas turbines must be modified to account for the lower Btu value of landfill gas. The standard modification is to enlarge the fuel supply system on the turbine. Emissions are a major factor in choosing to use a gas turbine instead of other gas to electricity options. Gas turbine emissions of NOx are orders of magnitude better than internal combustion engines and almost equivalent to flares and boilers[9]. The CO emissions from turbines are again much better than internal combustion engines and intermediate to boilers and flares. The benefits of installing gas turbines are their relatively maintenance free operation and their beneficial emissions profile; unfortunately, the benefits are not without a large up front capital cost and until micro-turbine technology becomes more proven the need for large gas production rates.

4.1.4 Steam Rankine Cycles employing Steam Turbines

Steam Rankine cycles employing steam turbines are in use in some of the largest LFGTE facilities in California, such as Puente Hills in Los Angeles County, in size from 9 MW_e to 50 MW_e. Steam turbines benefit greatly from economies of size; therefore, the applications of the technology have been limited to landfills with very large gas production rates. The landfill gas is burned in a boiler to produce high-pressure steam, and the steam is then used to drive a large turbine genset. Steam turbine LFGTE facilities gain the benefit of the outstanding emissions profile of a boiler and the excellent power generation efficiency of a steam turbine. The obstacles to the use of steam turbine LFGTE facilities are great; indeed, the massive capital of steam turbine LFGTE facilities and the need for large gas production rates to support the capital costs are generally insurmountable obstacles.

4.1.5 Other LFGTE Technologies

4.1.5.1 Microturbines

Microturbine technology is important to the LFGTE industry, appears to be well suited to small gas production rates (small or older landfills), and its emission profile is acceptable for applications in many locations that other LFGTE technologies are unable to serve. The typical sizes of commercially available microturbines are between 30 kW and 100 kW. The emissions of NOx and CO can be much less than other technologies, especially reciprocating engines. An advantage of microturbine technology is its non-labor-intensive operation; unfortunately, the labor advantage of microturbines is often lost when the gas treatment facilities are included. Moreover, the current capital cost of microturbines is high in comparison with other more developed LFGTE technologies.

4.1.5.2 Fuel Cells

National Aeronautics and Space Administration (NASA) initially developed fuel cell technology for space application, but after NASA completed the initial research and development, private industry has taken the lead in developing fuel cells for commercial sale. Fuel cells produce power by an electrochemical process that catalytically reacts hydrogen and oxygen and directly produces DC electricity, heat, CO_2, and water. For AC power applications, an inverter is used to convert the DC power. There are currently two types of fuel cells commercially available for landfill applications: molten carbonate fuel cell (MCFC) and

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[9] Suggested Control Measure for Landfill Gas Emissions. 1990. Prepared by California Air Resources Board, Stationary Source Division.

phosphoric acid fuel cells (PAFC). The MCFC has a higher potential efficiency than the PAFC, but the PAFC is further along in its development than the MCFC. Fuel cells are made up of three main components: 1) the fuel reformer, 2) the fuel cell stack, and 3) the inverter that converts the DC power from the fuel cell stacks to AC power for the grid. The reformer is used to produce hydrogen from methane in LFG. In addition, fuel cells require a clean fuel source; indeed, landfill gas contains many sulfur and halide compounds that contaminate catalysts in the fuel reformer and stack if not removed first. However, the emission profile of fuel cells is very good; in fact, the emissions of NO_x and CO from the fuel are almost zero.

Advantages of fuel cell technology include the high efficiency in converting gas to energy, the low noise, and the ease of operation and maintenance. The disadvantage involved in the implementation of fuel cell technology is the high capital cost and the complex, expensive gas pretreatment facilities. The commercially available units are 200kW and 300kW in size, which currently limits the size of facility that fuel cells can be employed in.

4.2 Existing LFGTE Projects and Technologies in California

Currently, 51 LFGTE projects operate in California today, using many different technologies to convert landfill gas to electricity. The different technologies represented in existing LFGTE projects in California include:

- 32 reciprocating engine facilities with a combined electrical generation capacity of 112 MW_e,
- seven direct use facilities (use of medium Btu LFG in burners and boilers),
- five gas turbine facilities with a combined electrical generation capacity of 10 MW_e,
- three steam turbines with a combined electrical generation capacity of 31 MW_e,
- two combined cycle (gas and steam turbines in a combined cycle) with an electrical generation capacity of 57 MW_e, and
- two pipeline use facilities.

The existing LFGTE facilities in California are summarized in Table 5. Map 2 shows the locations, capacities, and the types of existing LFG to electricity projects in California. Map 3 shows the locations, capacities, and the type of direct landfill gas use facility. The complete data set for landfills currently converting landfill gas into electricity and heat is contained in Appendix 1. The Energy Commission conducted a survey in 2001 to study the technologies and costs of LFGTE projects in California. Observations from the survey are described below.

Table 5. Existing LFGTE facilities in California

Technology	Number of landfills In California	Electrical Capacity (MW)
Direct Use	7	
Gas Turbine	5	10
Steam Turbine	3	31
Combination Cycle	2	57
Reciprocating Engine	32	112
Pipe line use	2	

4.2.1 GasTurbine

Gas turbines are in use at five of the 51 LFGTE facilities in California. Based on the Energy Commission's survey, the five facilities have gas production rates that range from 0.5 to 4 MM scf/day and generate electricity at capacities of 0.3 to 6 MW_e. The capital cost for electrical generation and gas collection facilities per kW generated averages $3500 per kW_e as shown in Figure 2. From the Energy Commission's survey data, it appears that for medium size facilities (1-5 MW_e) the capital cost per kW generated is high. Gas turbines become more economically viable (when examining capital cost only) as the facility size increases from medium size to large facilities (from about 5 to 18 MW).

4.2.2 Steam Cycles

Steam cycle gas production facilities are employed at three of the 51 LFGTE in California. According to the Energy Commission's survey, the sizes of these three gas production facilities range from 7 to 10 MM scf/day and produce electricity at capacities of 5 to 20 MW_e. For steam turbines in California, the capital cost of gas collection and electrical generation facilities averages $3500 per kW generated as shown in Figure 2. From the Energy Commission's survey, the capital cost per kW generated drops dramatically as the size of facility grows to above 10 MW.

4.2.3 Reciprocating Engines

Reciprocating engine technology is used at 32 of the 51 LFGTE facilities operating in California. With so many facilities in California, the range of gas collection rates and electrical generation rates is large. From the Energy Commission's survey, gas production rates range from approximately 0.5 to 12 MM scf/day and rates of electrical generation range from 0.9 to 10 MW_e. From the surveyed facilities in Figure 3, there are definite trends in the capital cost per kW generated. The most visible trend is of increasing investment per kW generated as the size of reciprocating engine facility (in kW) is increased from 3 to 10 MW_e. Indeed, it appears that it may be a better investment (capital cost $/kW) to move to other technology (gas turbine or steam turbine) as the size of the facility reaches approximately 10 MW_e.

4.2.4 Steam Boiler

In California, 2 of the 51 LFGTE facilities are using steam boilers. The Industrial Hills Sheraton is characteristic steam boiler LFGTE facilities. The landfill at Industrial Hills has approximately 1 million tons of MSW in place,[13] and the facility is closed to new dumping. Approximately 364,000 scf/day[14] of landfill gas being collected at this time. The gas is collected by vertical wells and delivered to the steam boiler system. The boilers, manufactured by Cleaver-Brooks and Kewanee & Parker, are used for producing hot water for laundry and to heat the hotel/convention center. The cost of the boiler and its associated gas collection system is almost $1.5 million.[10]

4.2.5 Comparison of LFGTE Projects and Technologies in the California and U.S.

Figure 3 shows the cost of LFGTE facilities in the U.S. including California. The trends in the U.S. are similar to those in California. In California, reciprocating engines appeared to be the best available option (pending further commercialization of microturbines and fuel cells) for facilities up to approximately 10 MW_e in size, and this trend appears to hold true for the rest of the U.S.. When looking at facilities sized from around 10 MW_e up to approximately 18 MW_e, the data favor the use of gas turbines. Above 18 MW_e, steam cycles are mostly used although combined cycles ae also used and have low investment per kW generation. Table 7 shows recommended facility size and technology based on the studies from Energy Commission's survey and GAA annual report.[10]

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[10] Methane Recovery from Landfill Yearbook 1999-2000.

Table 6. Reciprocating Engine Facilities in California (Energy Commission's Survey, 2001)

Facilities	Capital Cost of Gas Collection Facilities ($/kW)	Capital Cost of Electrical Facilities ($/kW)	Total Capital Cost ($/kW
A	$242	$364	$606
B	$640	$300	$940
C	$263	$1,052	$1,316
D	$238	$1,190	$1,429
E	$341	$1,136	$1,477
F	$357	$1,357	$1,714
G	$467	$1,333	$1,800
H	$526	$1,316	$1,842
I	$926	$926	$1,852
J	$551	$1,425	$1,976
K	$640	$1,515	$2,155
L	$1,405	$5,405	$6,811

Table 7. Trends of Facility Size and Technology Used in the U.S.

Facility Size (MW)	Recommended Technology
Less than 10	Reciprocating Engine
10 to 18	Gas Turbine
Greater than 18	Steam Turbine or Combination

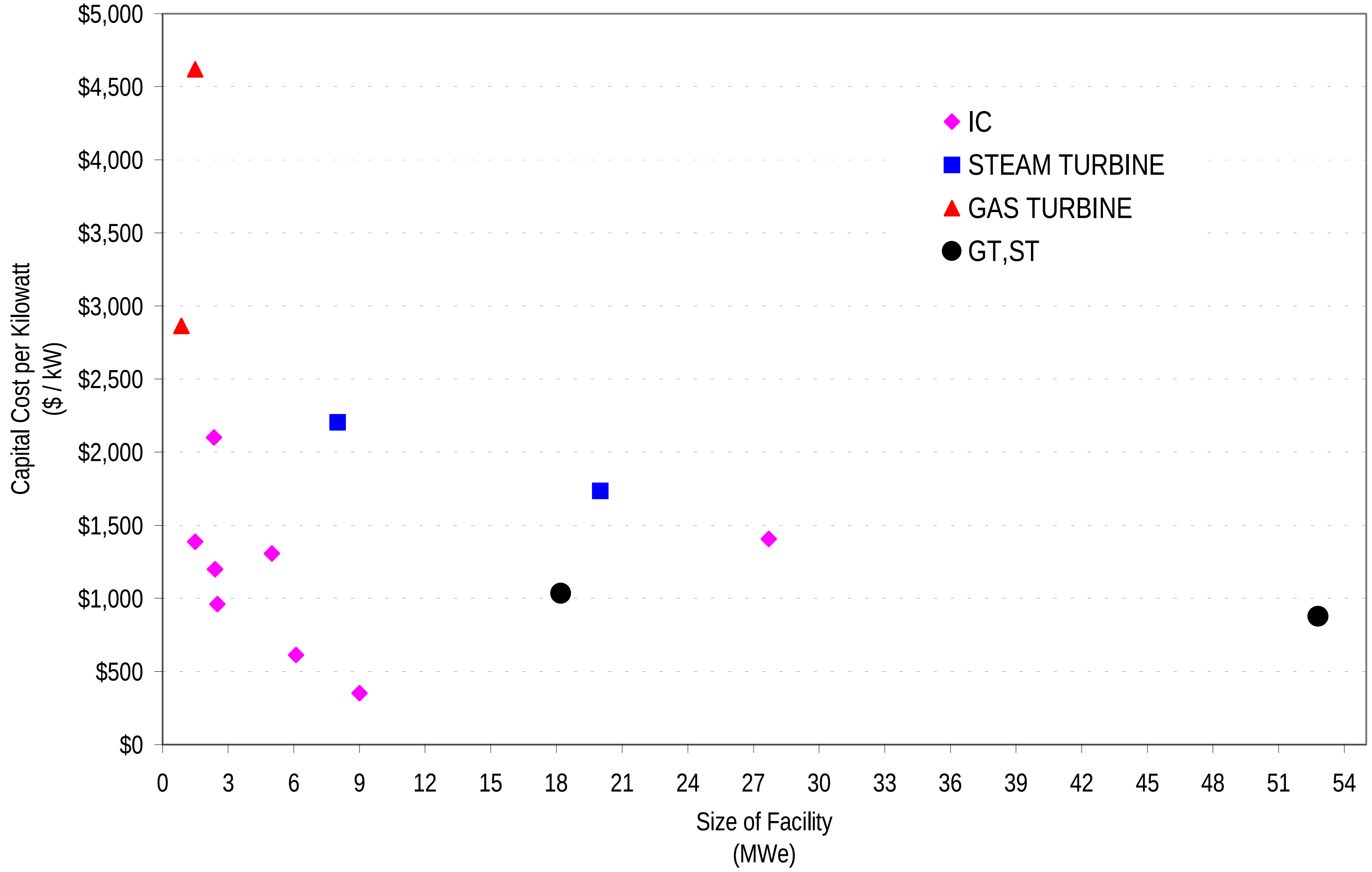


Figure 2: CapitalCosts vs. Facility Size (U.S., 2001)

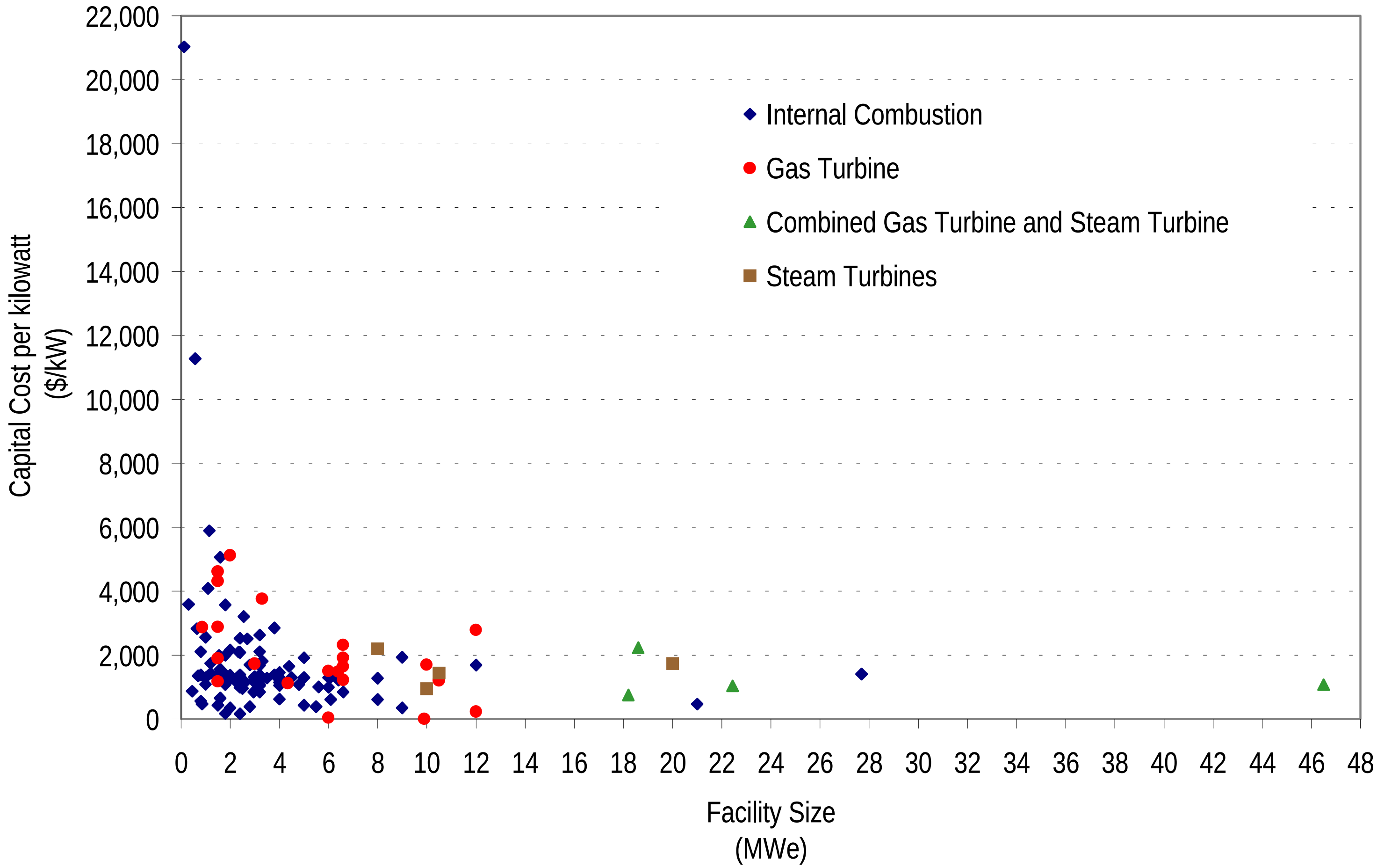
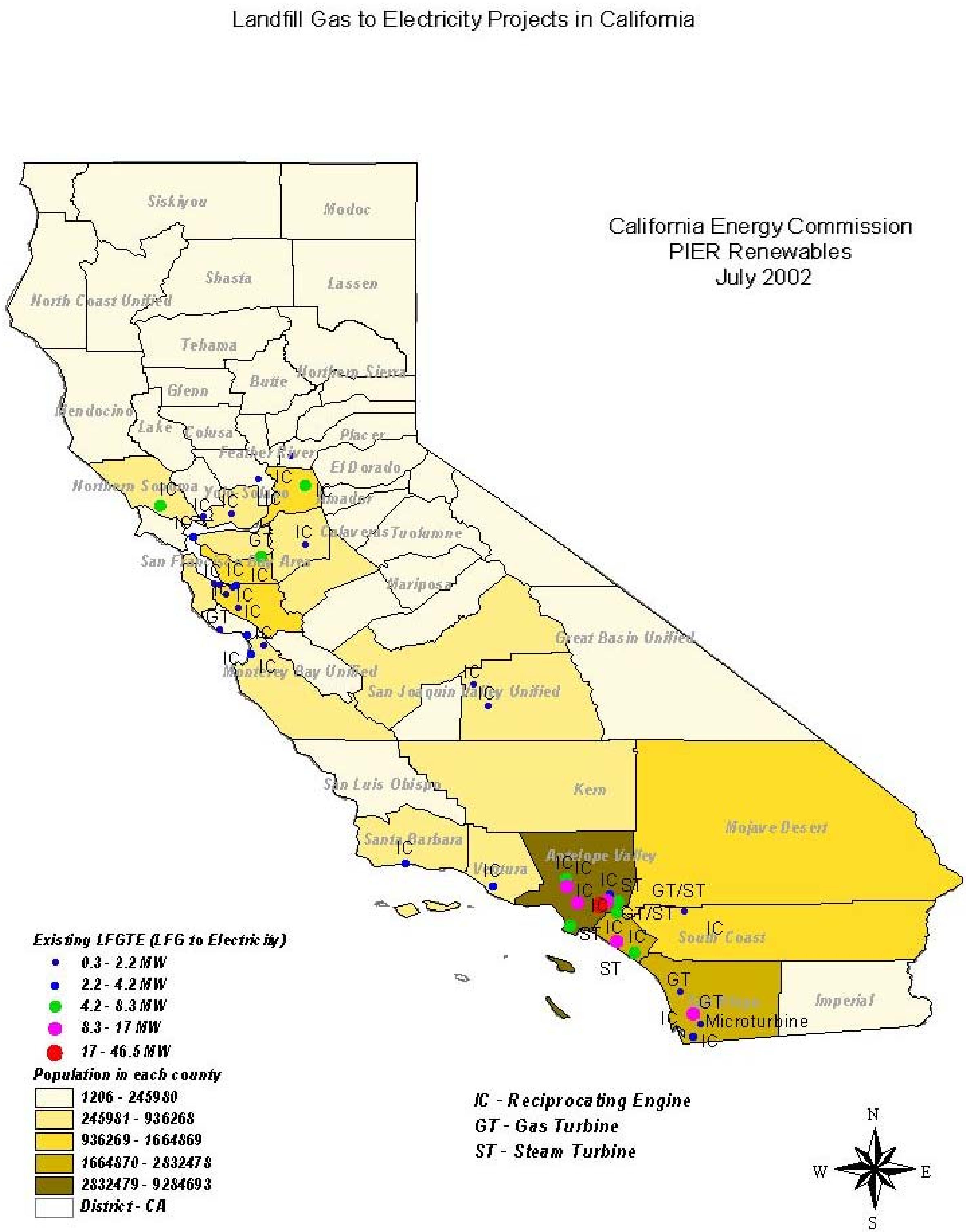
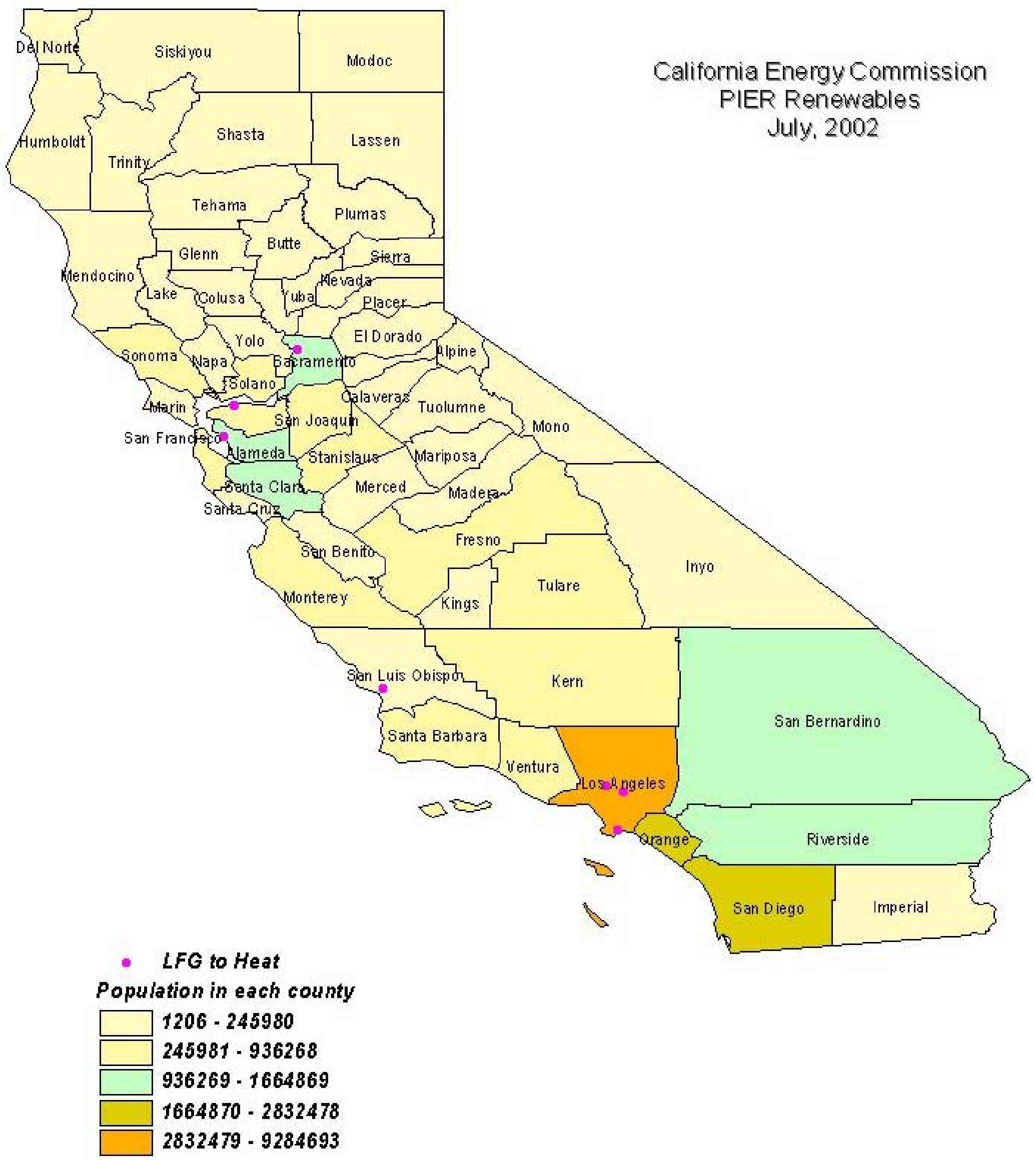


Figure 3. Capital Cost of Electrical Facilities vs. Facility Size (Surveyed California Facilities, 2001)



Map 2. Existing LFG to electricity projects in California

Landfill Gas to Heat Projects in California



Map 3. Existing LFG to heat projects in California

4.3 Planned LFGTE Projects in California

Twenty six LFGTE projects are planned in California today. As shown in Table 8, the different technologies represented include 14 reciprocating engine facilities, three direct use facilities, one pipeline use facility, and one LNG for vehicle facility. Five facilities have unstated technologies. Map 4 shows the locations and type of planned energy production facility at the landfills. Appendix II contains complete data for landfills that are currently planning LFGTE systems in California.

Table 8. Planned LFGTE Projects in California

Technology	Number of Landfills in California	Electrical Capacity (MW)
Direct Use	3	
Microturbine	1	0.6
Gas Turbine	1	10
LNG	1	
Reciprocating Engine	14	28.8
Pipeline use	1	
Unstated	5	

Map 4. Landfills with Planned LFGTE Projects in California

5.0 POTENTIAL DEVELOPMENT OF LFGTE PROJECTS IN CALIFORNIA

5.1 Potential Development from Landfills Flaring Landfill Gas

In California today, 70 landfills are flaring the LFG they are producing. These 70 landfills have the potential for producing approximately 66 MW_e of electricity. The three large flaring landfills (> 5 MW_e) - Calabasas LF, Sunshine Canyon, and Operating Industries (OII) (Federal NPL Site) – have approximately 32 MW_e of potential electrical capacity. The eight medium sized landfills (1-5 MW_e) have approximately 14 MW_e of potential electrical capacity. The electricity potential from the rest of 59 flaring landfills that are less than 1 MW_e in size is approximately 21 MW_e. Figure 4 and Table 9 show the number of landfills that are flaring landfill gas, their range of size, and electricity potential. Complete data for landfills flaring LFG are contained in Appendix III. Locations of landfills that flare their landfill gas are shown in Map 5.

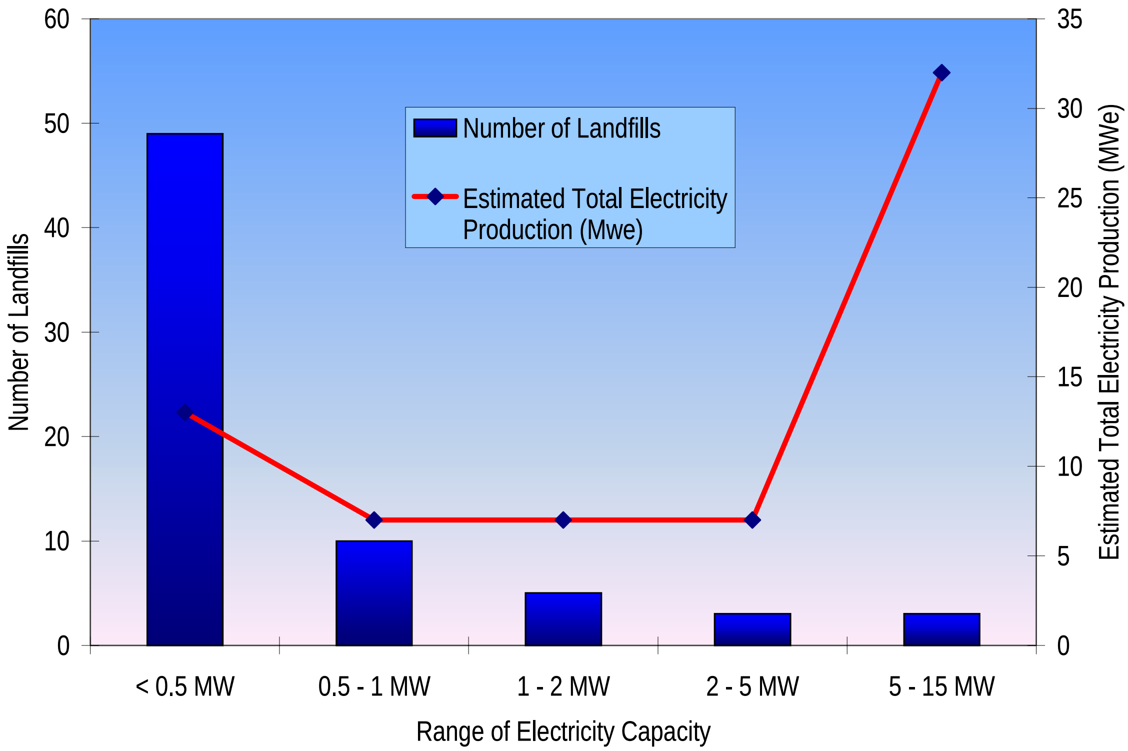
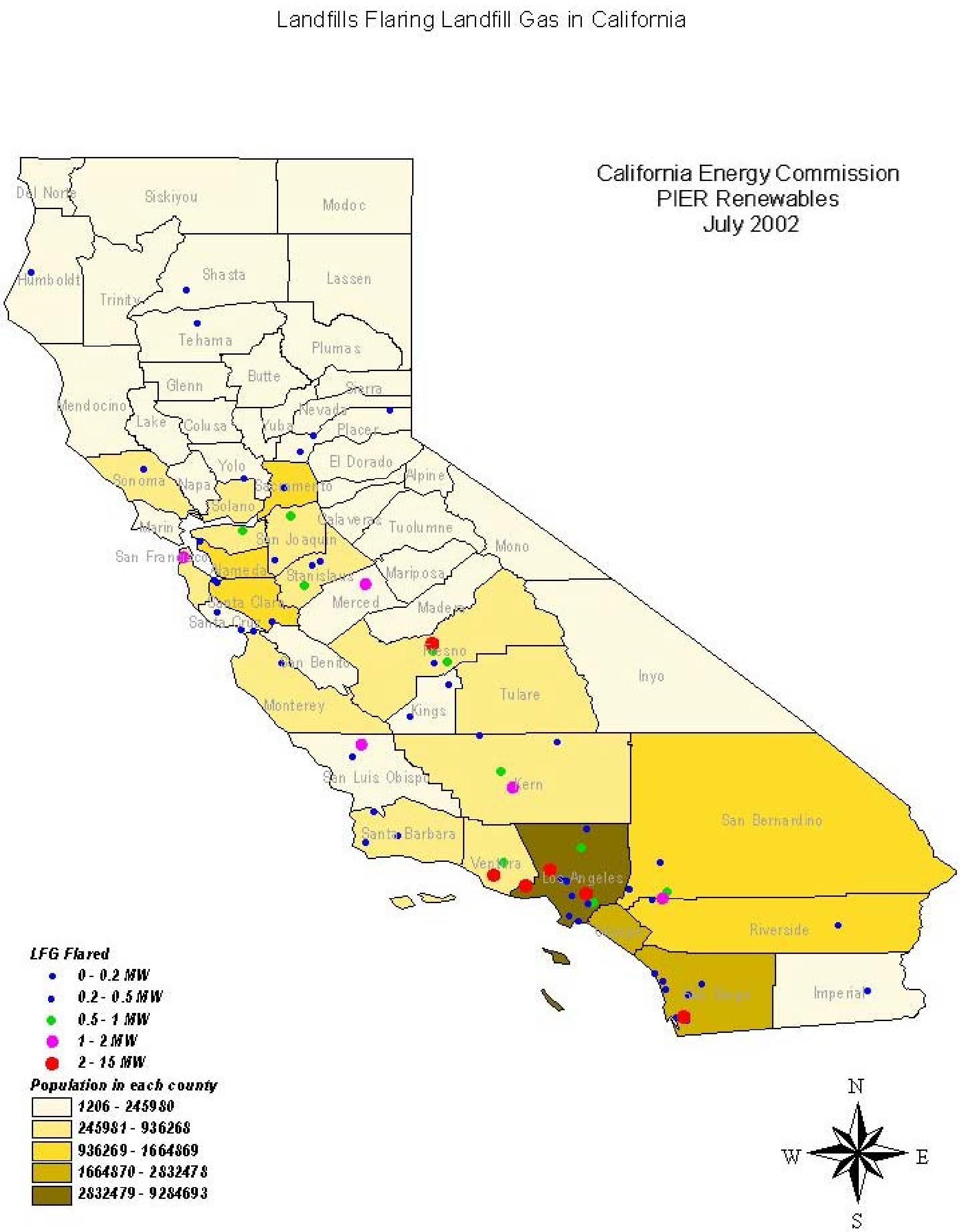


Figure 4. Landfills Currently Flaring LFG in California

Table 9. Landfills currently flaring LFG in California

Range of Electrical Capacity (MW_e)	Number of Landfills	Estimated Electricity Production (MW_e)
< 0.5	49	13
0.5 - 1	10	7
1 - 2	5	7
2 - 5	3	7
5 - 15	3	32
Total	**70**	**66**



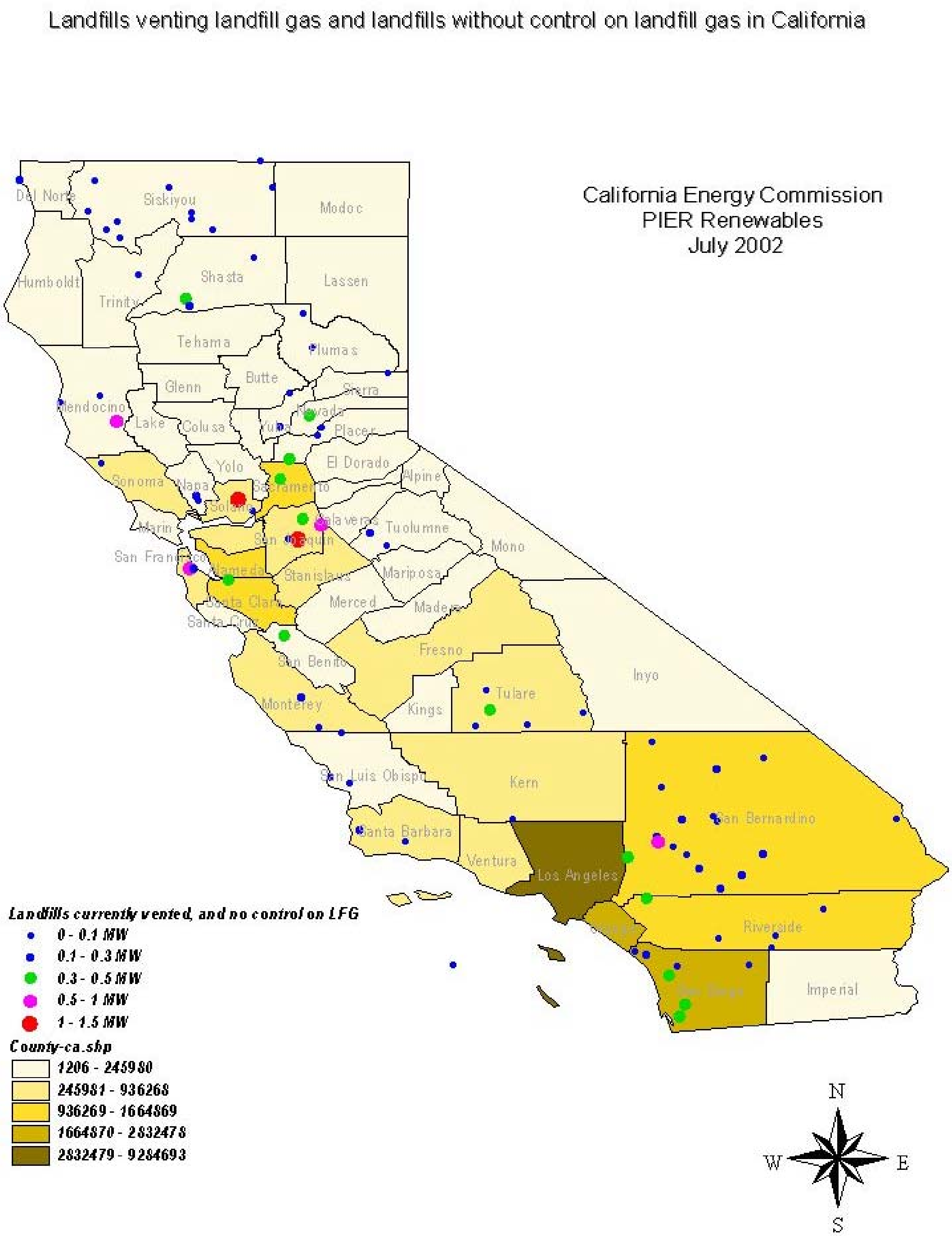
Map 5. Landfills flaring LFG in California

5.2 Potential Development from Landfills wityout Controlling the Landfill Gas Produced

In California today, 164 landfills either do not have landfill gas control systems or are venting the landfill gas generated. These 164 landfills have the potential for producing approximately 31 MW_e of electricity. Number of landfills and generating capacity by size range are listed in Table 10. The complete data for venting landfills are contained in Appendix IV. Locations of the landfills that vent landfill gas are shown in Map 6.

Table 10. Landfills Currently Venting LFG in California

Range of Electricity Capacity	Number of Landfills	Estimated Electricity Production
< 0.1 MW	103	5 MW
0.1 - 1 MW	56	19 MW
1 - 1.5 MW	5	7 MW
Total	**164**	**31 MW**



Map 6. Landfills venting landfill gas and landfill without control on LFG in California

6.0 SUMMARY OF OPPORTUNITIES FOR POTENTIAL DEVELOPMENT OF LFGTE IN CALIFORNIA

Opportunities for large LFGTE development:

- New sites that currently flare LFG - three sites with a total of 32 MW potential

Opportunities for medium LFGTE development:

- New sites that currently flare LFG - eight sites with a total of 14 MW potential
- New sites that currently vent LFG - five sites with a total of 7 MW potential

Opportunities for small LFGTE development:

- New sites that currently flare LFG - 59 sites with a total of 21 MW potential
- New sites that currently vent LFG - 159 sites with a total of 24 MW potential

7.0 BENEFITS OF LFGTE DEVELOPMENT IN CALIFORNIA

7.1 Energy Benefits

Landfill gas is a renewable energy resource and can be generated continuously if the landfill and landfill gas recovery system are well designed and operated. The supply of landfill gas can also reduce the state's dependency on fuel oil. The potential new power generation capacity from landfill gas in California is about 181 MW_e, which include 39 MW_e from planned LFGTE systems, 65 MW_e from the 70 landfills currently flaring LFG, 31 MW_e from 164 landfills currently venting LFG, and 45 MW_e from expanding existing LFGTE systems in California.

7.2 Environmental Benefits

Utilization of landfill gas brings environmental benefits in improving air quality and reducing odors. Reducing methane emissions diminishes local safety hazards from the potential build up and explosion of methane.

7.3 Economic Benefits

The development of landfill gas to energy technology will benefit local communities in both jobs and revenues. The economics of a landfill gas energy recovery project depend on many factors, including landfill gas quantity and quality, local energy prices, equipment choice, and other non-price factors, such as improvement on environment.

8.0 EXISTING ISSUES FOR LFGTE DEVELOPMENT IN CALIFORNIA

8.1 Technical Issues

8.1.1 Gas Production Rate

It is difficult to accurately predict landfill gas production rates, which can change from site to site, and are affected by many factors, such as type of wastes, the age of the landfill, temperature changes between winter and summer, annual precipitation, and moistiure in the landfill.

8.1.2 Size Selection

Difficulties exist when sizing the electricity generator because of the variations of landfill gas production rate with the landfill age and over time. A landfill may take several years before the gas production rate becomes sufficient to produce electricity for the LFGTE system. Unfortunately, with time, landfill gas production rate declines, as does the quality of the landfill gas. In addition to taking several years to produce gas at a sufficient rate to fuel a generator, that rate may last only a few years. The expected period over which gas will be produced may range from 50 to 100 years, but a usable gas production rate that can be utilized lasts for only 10 to 15 years. Underestimation of the production rate leads to a lost opportunity to generate electricity and earn revenues. However, overestimation will lead to occasions when there is an insufficient amount of landfill gas supply to run the generating equipment at its rated capacity.

8.2 Economic Issues

8.2.1 Tax

Tax issues, such as who takes the production tax credits (PTC), can affect the financial attractiveness of a project. The internal rate of return of a project, which is partly based on these tax credits, can be significantly increased. For private landfills, the PTC could be used in lieu of royalty and can be worth much more then the royalty income. The issue of PTC's has impacted development of landfill gas projects, especially by companies that have adequate taxable income to take advantage of available credits. In fact, projects that might otherwise show negative cash flow can become profitable with reduced tax load provided by the PTC.

8.2.2 Legal/Commercial Concerns

Legal/commercial concerns for project development include gas lease agreements (term of agreement, royalties, and environmental liabilities), and power purchase agreements (following interconnect priority procedures, curtailment provisions, pricing, and penalties). If limited partnerships are set up, the contracts must make provisions to allow a new legal entity to step in and take over all obligations of the primary developer. Utilities may require in some instances recourse to the original developer in the event that the partnership collapses or generates financial difficulites. The gas lease and the power purchase agreement should have the same time period.

8.3 Environmental Issues

Many of the adverse environmental effects of landfills are well documented. However, very little data are available concerning the environmental impact of landfill gas recovery and processing facilities.

8.3.1 Air Quality

A landfill gas recovery facility will have an air quality impact. For example, instead of reducing emission factors, IC engines emit NO_x, CO, and VOC at levels that are 4 times higher than flaring, as shown in Table 11. Boilers and gas turbines have competitive NO_x, CO, and VOC emission factors as compared with flaring. Difficulty may exist when applying for an air quality permit using an IC engine for LFGTE. A combined factor in air, water quality, and economic cost needs to be considered when making a decision on choosing a LFGTE technology. Landfills use non-combustion-based technologies, such as pipeline gas and fuel cell, emit significantly less pollution than the combustion-based systems. However, the cost of non-combustion based technologies is currently much higher.

Table 11. Emission factors for various landfill gas control technologies[11] (lb/MM Btu)

LFG Control Technology	NO_x	SO_x	CO	PM	VOC
Combustion-based					
Flare	0.05	0.001	0.19	0.07	0.039
Boiler	0.045	NA	0.005	0.005	0.050
IC Engine	0.220	NA	0.671	NA	0.147
Gas Turbine	0.07	NA	0.10	NA	0.007
Non-combustion based					
PAFC	0.0005	NA	0.002	NA	NA
LFGPU	0.04	NA	0.00009	0.00006	NA
LFG to methanol	0.05	0.001	0.019	0.07	0.039
LFG to CNG	0.03	0.002	0.066	0.0	0.0005
LFG to CO_2 and CH_4	0.05	0.001	0.019	0.07	0.039
LFG to pipeline CH_4	NA	NA	NA	NA	NA
LFG to LNG	NA	NA	NA	NA	NA

8.3.2 Water Quality

Leachate from landfills may be a source of groundwater pollution. Carbon dioxide (CO_2), produced during the decomposition of the solid wastes may contribute to leachate acidity or groundwater hardness. Condensate produced during landfill gas recovery and processing activities poses a potential water quality problem. Most California state and regional environmental policies prohibit the recycling of condensate within landfills, and the collected condensate must be disposed of elsewhere.[12]

8.4 Market Connection, Better Understanding of the Technology, and Joint Planning

8.4.1. Market Connection

A market must exist for the medium or high Btu fuel or the electricity produced by a LFGTE system. Difficulties often exist in negotiating power contracts with local utilities, as they are primarily interested in purchasing low-cost power without considering environmental concerns. The lack of suitable market exists in landfills due to lack of proximity to local power distribution lines or indutrical users.

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[11] Non-combustion landfill gas control technologies, March 1998. Prepared by Renaldo Rrooks, Mark Watkins, and Winston Potts, Emissions Assessment Branch Stationary Source Division, Air Resources Board, California Environmental Protection Agency.

[12] Bowerman, F.R., N.K. Rohatgi, K.Y. Chen, and R.A. Lockwood. 1977. A Case Study of the Los Angeles County Palos Verdes Landfill Gas Development Project. NTIS No. PB-272 241.

8.4.2 Better Understanding of the Technology

Several landfill gas recovery facilities were shutdown in California because of poor technical design and management. Although landfill gas energy recovery is a mature technology, close attention must be paid to choosing the right energy recovery facilities and knowledgable developers to ensure the success of the technology. For example, a gas engine must be modified to avoid corrosion caused by the landfill gas. Some landfill owners and operators may still not be aware of the potential for using LFG from their sites and they do not well understand the technology of landfill energy recovery. This is also true for decision-makers, such as local and regional governments.

8.4.3 Joint Planning

Different agencies, such as California Integrated Waste Management Board (CIWMB), California Air Resource Board (Cal-ARB), State Water Resource Control Board (SWRCB), and the Energy Commission have different interests and concerns on LFGTE technologies. Coordination among agencies is needed to ensure the potential of LFGTE is realized. Combined factors related to benefits from utilization of renewable energy and reduction of environmental pollution need to be considered.

9.0 ACTING ON POTENTIAL LFGTE DEVELOPMENT AT THE ENERGY COMMISSION

9.1 Supporting Commercially Available LFGTE Systems from Energy Commission's Renewable Energy Program

Per Senate Bill 90, the Energy Commission established a Renewable Energy Program beginning January 1998. The program is comprised of five accounts, each of which targets a different need within the renewable energy industry. The two accounts that directly provide funding to landfill gas projects in the state of California are the Existing Renewable Resources Account and the New Renewable Resources Account.

The New Account provides a total of $162 million in conditional funding to new renewable energy projects (built after September 1996) participating in the account. Twenty landfill gas projects are currently participating in the New Account, and by the end of the five-year funding period (Jan.1, 2007), these projects will have received a total of $28.3 million in funding. Currently, seven of the twenty landfill’s gas projects are on-line and receiving funding from the New Account. The Existing Account provides a total of $243 million in funding to existing renewable energy projects (built before September 1996). As of February 2000, landfill gas projects participating in the Existing Account have received a total of $2.18 million in funding. It is not certain yet how much funding landfill gas projects participating in the Existing Account will receive by the end of the funding period.

9.2 Supporting R&D of New LFGTE Technologies from CEC's PIER Renewables Program

The overall goal of the Public Interest Energy Research (PIER) Renewable program is to provide funding to support the development of advanced renewable energy technologies that will help make California's electricity more diverse and affordable. The PIER Renewable Program funds are being provided to facilitate development of linked renewable energy projects that act in a coordinated fashion to make electricity more affordable. Development efforts are to be focused towards making electricity more affordable for a specific electricity customer class, for electricity customers in a specific geographical location, or to help create a collection of renewable energy technologies, products, or services that enhance customer choice across customer class or location.

In 2001, the PIER Renewable program awarded a total of over $3.4 million to two landfill projects including Commonwealth landfill and SMUD-Yolo bioreactor projects under a programmatic solicitation. The outcome of the Commonwealth landfill project will be the successful operation of two bioreactor pilot projects. One bioreactor will be designed to use municipal solid waste (MSW) and source-separated organic waste materials; the other will be designed to use MSW or source-separated organic waste materials along with animal waste. Performance impropments will be measured by changing in methane production, estimation of direct reductions in CH_4 emissions, and indirect reductions in other criteria air emissions associated with displaced conventional generation; and assessment of changes in lifecycle costs of generation from landfill gas. The cumulative incremental gas production from both of these pilot reactors will be in the range of 1 to 5 MW_x equivalent power generations.

The SMUD-Yolo bioreactor landfill project will lead to the acceptance and commercialization of bioreactor technology throughout the state. As a result of this demonstration project and acceptance of the bioreactor landfilling concept by EPA and the state, many other public and private landfill owners and operators will be able to implement this technology at other sites. The technology is expected to improve the economics of landfill gas to electricity and yield more renewable landfill gas and provide many environmental benefits for nearly all regions in U.S.

A biogas targeted solicitation was released from the Energy Commission in April 2002. The goal of the solicitation is to utilize renewable resources from solid wastes including animal wastes as well as biosolids generated from other waste streams for environmental and economic benefits using advanced technologies in California. The solicitation targets include, but are not limited to landfill gas recovery, biogas generation and utilization from animal waste treatment facilities, food processing waste treatment facilities, and domestic and industrial wastewater treatment plants. A total of $5 million is available to the selected targets.

Appendix I. Existing LFGTE Projects in California (provided by California Integrated Waste Management Board and California Energy Commission, September 2001)

Facility Name	Estimated Closure Date	Landfill Gas Control & and Gas-to-Energy (LFGTE) Systems	LFGTE System Type and Estimated Production Capacity	LFGTE Project Developer	Estimated MSW Tons In-Place-2000	Data Source
Acme Sanitary LF	2001	Active-Flare/LFGTE	Direct Use (Boiler)	Acme Fill	7,000,000	CIWMB
All Purpose LF	1993	Active-Flare/LFGTE	Engine - 0.9 MW	Covanta [http://www.covantaenergy.com]	1,000,000	CEC
Altamont LF	2007 (expansion planned)	Active-Flare/LFGTE	Gas Turbine- 6.0 MW	IT Corporation	26,000,000	CEC
American Canyon LF	2000	Active-Flare/LFGTE	Engine- 1.4 MW	GRS [http//:www.grsi.net]	2,100,000	CEC
Ascon Sanitary LF	1988	Active-Flare/LFGTE	Direct Use (Boiler)		2,400,000	CIWMB
Austin Rd. LF	2053	Active-Flare/LFGTE	Engine- 0.8 MW	Covanta [http://www.covantaenergy.com]	2,000,000	CIWMB
Azusa LF	2009	Active-Flare/LFGTE	Engine- 3 MW	EDI	11,000,000	CIWMB
Badlands DS	2018	Active-Flare/LFGTE	Engine- 1.14 MW	County of Riverside [http://www.rivcowm.org]	2,500,000	CEC
Bailard LF	1996	Active-Flare/LFGTE	Engine- 3.3 MW	Covanta [http://www.covantaenergy.com]	3,800,000	CIWMB
BKK West Covina DS	1996	Active-Flare/LFGTE	Gas and Steam Turbine- 10.6 MW	Minnesota Methane [http://www.nrgenergy.com]	38,000,000	CEC
Bradley Ave East & West	2000	Active-Flare/LFGTE	Direct Use (Boiler)	WMI [http://www.wm.com]	20,000,000	CIWMB

Buena Vista DS	2021	Active-Flare/LFGTE	Engine- 3.0 MW	Emcon/ Perennial [http://www.emconinc.com]	2,000,000	CEC
Central LF		Active-Flare/LFGTE	Engine- 6 MW	County of Sonoma [http://www.recyclenow.org]	10,000,000	CEC
City of Santa Cruz LF	2037	Active-Flare/LFGTE	Gas Turbine- 0.65 MW	GRS [http//:www.grsi.net]	1,500,000	CEC
Coastal LF (aka Santa Clara LF)	1989	Active-Flare/LFGTE	Engine- 5.6 MW	Covanta [http://www.covantaenergy.com]	2,500,000	CIWMB
Cold Canyon	2017	Active-Flare/LFGTE	Direct Use (Boiler)		3,400,000	CIWMB
Coyote Canyon SLF	1992	Active-Flare/LFGTE	Steam Turbine- 17.0 MW	GRS [http//:www.grsi.net]	27,000,000	CEC
Crazy Horse LF	2004	Active-Flare/LFGTE	Engine- 1.4 MW	Covanta [http://www.covantaenergy.com]	1,100,000	CIWMB
Davis Street	1980	Active-Flare/LFGTE	Pipeline Use	GSF Energy [http://www.gsfenergy.com]	13,000,000	CIWMB
Guadalupe SLF	2020	Active-Flare/LFGTE	Engine- 2.2 MW	GRS [http//:www.grsi.net]	3,000,000	CEC
Industry Hills Sheraton Resort	1988	Active-Flare/LFGTE	Direct Use (Boiler)	City of Industry [http://www.cityofindustry.org]	>1,000,000	CEC
Jamacha	1988	Active-Flare/LFGTE	Microturbine- 300 KW		1,800,000	CIWMB
Kiefer LF	2035	Active-Flare/LFGTE	Engine- 8.3 MW	LES/DTE Biomass	16,000,000	CEC
Lopez Canyon LF	1996	Active-Flare/LFGTE	Engine- 5.4 MW	NEO [http://www.nrgenergy.com]	19,000,000	CEC
Marsh Road	1988	Active-Flare/LFGTE	Engine- 1.9 MW	GRS [http//:www.grsi.net]	5,000,000	CEC
Miramar SWLF	2011	Active-Flare/LFGTE	Engine/Direct Use/Vehicle Fuel (LNG)- 9.5 MW	Minnesota Methane [http://www.nrgenergy.com]	9,000,000	CEC

Mission Canyon LF (aka Mountaingate)	1981 1965	Active-Flare/LFGTE	Direct Use (Boiler)	GSF Energy [http://www.gsfenergy.com]	26,800,000	CIWMB
Monterey Peninsula LF	2084	Active-Flare/LFGTE	Engine- 3 MW	ZAPCO	6,200,000	CEC
Newby Island	2016	Active-Flare/LFGTE	Engine- 4.2 MW (Direct use planned)	GRS [http//:www.grsi.net]	2,500,000	CEC
Olinda Alpha SLF	2013	Active-Flare/LFGTE	Engine- 5 MW	NEO [http://www.nrgenergy.com]	33,000,000	CEC
Otay SWLF	2027	Active-Flare/LFGTE	Engine- 3.7 MW	Covanta [http://www.covantaenergy.com]	10,000,000	CIWMB
Palo Alto RDS	2011	Active-Flare/LFGTE	Engine- 1 MW	WMI [http://www.wm.com]	700,000	CIWMB
Palos Verdes	1980	Active-Flare/LFGTE	Steam Turbine- 6 MW	LACSD [http://www.lacsd.org]	23,573,729	CEC
Penrose Pit	1988	Active-Flare/LFGTE	Engine- 9.3 MW	Covanta [http://www.covantaenergy.com]	9,000,000	CIWMB
Potrero Hills	2059	Active-Flare/LFGTE	Engine- 1 MW	Nove	3,500,000	CIWMB
Prima Descha SLF	2040	Active-Flare/LFGTE	Engine- 6.0 MW	NEO [http://www.nrgenergy.com]	24,000,000	CEC
Puente Hills LF	2003	Active-Flare/LFGTE	Gas and Steam Turbine/Direct Use/Vehicle Fuel (LNG)-46.5 MW	LACSD [http://www.lacsd.org]	88,000,000	CEC
Sacramento City LF	1994	Active-Flare/LFGTE	Direct Use- 1.6 mmscfd	GRS [http//:www.grsi.net]	3,900,000	CIWMB
San Marcos LF	1997	Active-Flare/LFGTE	Gas Turbine- 1.3 MW	GRS [http//:www.grsi.net]	5,600,000	CEC
Scholl Canyon LF	2014	Active-Flare/LFGTE	Pipeline Use	Palmer	24,000,000	CIWMB

Sheldon-Arleta	1974	Active-Flare/LFGTE	Engine- 4.1 MW	Covanta [http://www.covantaenergy.com]	3,000,000	CIWMB
Spadra LF	2000	Active-Flare/LFGTE	Steam Turbine- 8.3 MW	LACSD [http://www.lacsd.org]	17,000,000	CEC
Sunnyvale LF	1994	Active-Flare/LFGTE	Engine- .925 MW	City of Sunnyvale [http://www.ci.sunnyvale.ca.us/recycle]	2,300,000	CEC
Sycamore SW LF	2015	Active-Flare/LFGTE	Gas Turbine- 1.3 MW	GRS [http//:www.grsi.net]	9,000,000	CEC
Tajiguas LF	2006	Active-Flare/LFGTE	Engine- 2.97 MW	NEO [http://www.nrgenergy.com]	5,000,000	CEC
Toyon	1986	Active-Flare/LFGTE	Engine- 9 MW	Ogden [http://www.covantaenergy.com]	16,000,000	CIWMB
Visalia DS	2019	Active-Flare/LFGTE	Engine- 1.55 MW	NEO [http://www.nrgenergy.com]	1,500,000	CEC
W Contra Costa LF	2002	Active-Flare/LFGTE	Engine- 3 MW	Bay Environmental Management (formerly Nove)	7,400,000	CEC
Western Regional		Active-Flare/LFGTE	Engine- 1 MW	WPWMA [http://www.westbioenergy.org]		CEC
Woodville DS	2039	Active-Flare/LFGTE	Engine- 1 MW	NEO [http://www.nrgenergy.com]	2,000,000	CIWMB
Yolo Co. Central LF	2020	Active-Flare/LFGTE	Engine- 1.65 MW (Expansion to 12 MW and Microturbine planned for Bioreactor LF project)	NEO [http://www.nrgenergy.com]	4,000,000	CEC

Appendix II. Planned LFGTE Systems in California (provided by the California Integrated Waste Management Board and California Energy Commission, September 2001)

Facility Name	Estimated Closure Date	Landfill Gas Control &and Gas-to-Energy (LFGTE) Systems	LFGTE System Type and Estimated Production Capacity	LFGTE Project Developer	Estimated MSW Tons In-Place-2000	Source Data
Blythe DS	2033	Active-Flare (LFGTE Planned)			1,200,000	CIWMB
Chateau Fresno LF	1996	Active-Flare (LFGTE Planned)	Engine- 2.6 MW (planned)	EDI	3,800,000	CEC
Chiquita Canyon	2019	Active-Flare (LFGTE planned)	Pipeline Use (planned)		5,000,000	CIWMB
Coachella Valley DS	1997	Active-Flare/LFGTE proposed (LFGTE planned)	Engine- 1 MW (planned)		2,200,000	CEC
Colton LF	2006	Active-Flare (LFGTE planned)	Direct Use- 2.5 MW/1.8 mmscfd (planned)	NEO/BAS [http://www.nrgenergy.com]	4,500,000	CEC
Corinda Los Trancos LF (Ox Mtn)	2023	Active-Flare (LFGTE planned)	Gas Turbine- 10 MW (planned)	GRS [http//:www.grsi.net]	9,000,000	CEC
Double Butte DS	1995	Active-Flare (LFGTE planned)			3,800,000	CEC
Edom Hill DS	2002	Active-Flare (LFGTE planned)	Engine- 2 MW (planned)		2,000,000	CEC
El Sobrante SWLF	2030	Active-Flare (LFGTE planned)	Engine- 1.2 MW		5,000,000	WM meeting with CEC
Fairmead LF	2026	Active-Flare (LFGTE planned)	Microturbines- .60 MW		500,000	CEC SURVEY

Fontana RDS (Mid-Valley)	2033	Active-Flare (LFGTE planned)	Direct Thermal- 3.8 MW/2.8 mmscfd (planned)	NEO/BAS [http://www.nrgenergy.com]	8,000,000	CEC
Frank R. Bowerman	2028	Active-Flare/LFGTE (LFGTE planned)	Vehicle Fuel (LNG)	Ecogas	20,000,000	CIWMB
Keller Canyon LF	2037	Active-Flare (LFGTE planned)	Engine- 3.9 MW (planned)	EDI	8,000,000	CEC
Kirby Canyon LF	2025	Active-Flare (LFGTE planned)	Engine- 1.28 MW		2,500,000	WM meeting with CEC
Lamb Canyon DS	2024	Active-Flare (LFGTE planned)	Engine- 1 MW (planned)		3,000,000	CEC
Mead Valley DS	1997	Active-Flare/LFGTE proposed	Engine- 1 MW (planned)		2,000,000	CEC
Milliken	2001	Active-Flare (LFGTE planned)	Engine- 5 MW (planned)	NEO/BAS [http://www.nrgenergy.com]	11,000,000	CEC
Ostrom Road SLF	2038	No (LFGTE planned/candidate per USEPA)			700,000	CIWMB
Redwood SLF	2039	Active-Flare	Engine- .96 MW	WMI [http://www.wm.com]	4,000,000	WM meeting with CEC
San Timoteo SWDS	2016	Active-Flare proposed (LFGTE planned/candidate per USEPA)	Engine- 2.1 MW (planned)	NEO/BAS [http://www.nrgenergy.com]	2,000,000	CIWMB
Santiago Canyon SLF	1995	Active-Flare (LFGTE planned/candidate per USEPA)			11,000,000	CIWMB
Tri-Cities LF	2002	Active-Flare (LFGTE planned/candidate per USEPA)	Engine-.96 MW	WMI [http://www.wm.com]	6,500,000	WM meeting with CEC
Union Mine DS	2012	Active-Flare/LFGTE	Engine- 1.3 MW	El Dorado Co. http://www.co.el-	1,500,000	CEC

				dorado.ca.us]		
Vasco Road LF	2016	Active-Flare (LFGTE planned/candidate per USEPA)	Engine- 4.5 MW (planned)	NEO [http://www.nrgenergy.com]	10,000,000	CIWMB
Yuba Sutter Disposal Area LF (YSDA)	1997	No (LFGTE candidate per USEPA- recommend remove from list- site is abandoned and was remediated by CIWMB)			250,000	CIWMB
Yuba Sutter Disposal Inc. LF (YSDI)	1997	Passive Venting- North Area Active Venting proposed (8/98) for South Area. (LFGTE planned/candidate per USEPA)	Direct Use (planned)		1,300,000	CIWMB

Appendix III. Landfills Currently Flaring LFG in California (provided by the California Integrated Waste Management Board and California Energy Commission, September 2001)

Facility Name	Estimated Closure Date	Max. Waste Footprint Acres	Estimated MSW Tons In-Place-2000	Estimated Electrical Potential (MW) (CEC)	MSW Tons Disposed-2000
Antelope Valley	2001 (expansion planned)	57	1,700,000	0.776	166,424
Arizona St.	<1/1/88	64	500,000-1,000,000	0.457	0
Arvin SLF	2008	143	3,200,000	1.461	71,735
Bakersfield	<1/1/88		>1,000,000	0.457	0
Ben Lomond WDS	1994	24	700,000	0.320	0
Berkeley LF	1983	90	>1,000,000	0.457	0
Bonzi LF	1991	35	500,000	0.228	14,350
Burbank LF #3	2053	49	500,000	0.228	41,433
Calabasas LF	2018	310	19,000,000	8.676	346,690
California St. LF	2007	65	1,400,000	0.639	50,617
Chestnut Ave DS	1994	32	950,000	0.434	0
Chicago Grade	2018	36	350,000	0.160	40,949
China Grade SLF	1992	58	2,000,000	0.913	0
City of Fresno LF (Federal NPL Site)	1987	145	4,700,000	2.146	0
City of Santa Maria LF	2003	186	700,000	0.320	139,955
City of Watsonville	2023	31	500,000	0.228	30,494
Contra Costa SLF (aka Pittsburg or GBF LF)	1992	74	1,200,000	0.548	0
Corral Hollow	1995	30	500,000	0.228	0
Cummings Road LF	2007	38	560,000	0.256	11,747
Dixon Pit LF	1999	30	100,000	0.046	11,000

Eagle Mtn.	>2100	2247	0 (500,000,000 capacity construction to start 2005-10)	0.000	0
Eastern Regional LF	1994	36	500,000	0.228	0
Encinitas	<1/1/88	30	580,000	0.265	0
Fink Rd LF	2019	216	1,500,000	0.685	177,975
Foxen LF	2001	18	500,000	0.228	30,868
Gaffey St.	<1/1/88		<500,000	0.228	0
Gardena Valley #6 (Ford Center)	<1/1/88		500,000-1,000,000	0.457	0
Geer Road LF	1990	144	250,000	0.114	0
Hanford LF	1998	79	380,000	0.174	0
Harney Lane LF	1994	97	2,000,000	0.913	0
Healdsburg	1993	27	500,000	0.228	0
Hesperia RDS	2001	50	200,000	0.091	0
Highgrove LF	1998	71	2,900,000	1.324	0
Hillsborough	<1/1/88	16	350,000	0.160	0
Hillside LF	2001	30	2,500,000	1.142	95,938
Hwy 59 DS	2043	255	3,200,000	1.461	168,237
Johnson Cnyn LF	2045	80	200,000	0.091	49,311
Kern Valley LF	1997	31	230,000	0.105	<1,000
Kettleman Hills SLF	2023	43	300,000	0.137	184,548
Lancaster Waste Mgt.	2002 (expansion planned)	78	400,000	0.183	154,766
Lewis Rd. LF	2002	14	400,000	0.183	20,101
Lompoc LF	2047	63	500,000	0.228	43,573
Loomis Landfill	<1/1/88		<500,000	0.228	0
Loynes/Bixby	<1/1/88		<500,000	0.228	0
Maxon St.	<1/1/88		500,000-1,000,000	0.457	0

McFarland-Delano LF	1992	40	600,000	0.274	0
Meadow Vista LF	<1/1/88		<500,000	0.228	0
Mesquite Regional LF	>2100	2290	0 (500,000,000 capacity construction to start 2005-10)	0.000	0
Norwalk Dump	<1/1/88		500,000-1,000,000	0.457	0
Operating Industries (OII) (Federal NPL Site)	<1/1/88	190	22-30,000,000	13.699	0
Orange Ave.	2005	29	1,100,000	0.502	46,513
Pacheco Pass LF	2004	91	1,000,000	0.457	90,379
Palomar	<1/1/88		500,000-1,000,000	0.457	0
Paso Robles LF	2031	66	2,800,000	1.279	41,124
Pick Your Parts LF	<1/1/88		500,000-1,000,000	0.457	0
Poway	<1/1/88	12	165,000	0.075	0
Ramona LF	2006	46	500,000	0.228	58,791
Red Bluff LF	2003	33	750,000	0.342	44,452
Redding SLF (Benton)	1994	71	800,000	0.365	0
Santa Clara LF (next to All Purpose LF)			1,000,000	0.457	
Shoreline-Mtn. View (Vista)	1993	150	1,000,000	0.457	0
Simi Valley LF	2012	142	6,000,000	2.740	581,776
Sourtheast Regional	1990	67	1,300,000	0.594	0
South Chollas	<1/1/88	120	4,700,000	2.146	0
Sunshine Canyon	2004	215	20,000,000	9.132	1,485,832
Toland Rd. LF	2027	86	2,000,000	0.913	330,457
UC Davis LF	2032	53	350,000	0.160	13,256
Upland LF	<1/1/88		500,000-1,000,000	0.457	0
West Riverside	<1/1/88		500,000-1,000,000	0.457	0
Whittier- Savage Canyon	2039	132	2,000,000	0.913	87,950

Appendix IV. Landfills Currently Venting or with No Control on LFG in California (provided by the California Integrated Waste Management Board and California Energy Commission, September 2001)

Facility Name	Estimated Closure Date	Landfill Gas Control &and Gas-to-Energy (LFGTE) Systems	Estimated MSW Tons In-Place-2000	Estimated Electrical Potential (MW)	MSW Tons Disposed-2000
Alturas	2009	No	<100,000	0.046	<1,000
Amador Co. LF	2006	No	550,000	0.251	39,339
American Ave.	2028	No	2,200,000	1.005	591,359
Anderson LF	2049	Active-Venting	500,000	0.228	74,734
Annapolis LF	1995	No	<100,000	0.046	0
Anza DS	1999	No	100,000	0.046	0
Apple Valley DS	2004	No	100,000	0.046	0
Avenal LF	2039	No	750,000	0.342	9,828
B & J Drop Box	2055	No (Tier 2 NSPS/EG control measures required at 2025)	3,000,000	1.370	126,106
Baker RDS	1997	No	<100,000	0.046	0
Bakersfield SLF (Bena)	2038	No (Tier 2 NSPS/EG control measures required at 2015)	4,500,000	2.055	338,163
Balance Rock DS	1998	No	<100,000	0.046	0
Barstow RDS	2007	No	500,000	0.228	47,654
Bass Hill LF	2010	No	170,000	0.078	10,699
Beale AFB LF	1997	Passive Venting	400,000	0.183	0
Benton Crossing	2014	No	200,000	0.091	22,124
Benton SLF	2212	No	<100,000	0.046	<1,000
Berry Street Mall LF	1992	No	100,000	0.046	0
Berryessa Garbage	1992	No	<100,000	0.046	0
Bieber LF	1992	No	<100,000	0.046	0

Big Bear RDS	2002	No	250,000	0.114	35,497
Big Oak Flat LF	2002	No	<100,000	0.046	<1,000
Billy Wright LF	2009	No	500,000	0.228	48,631
Bishop Canyon LF	1969	Passive Venting and Air Injection	1,700,000	0.776	0
Bishop Sunland	2054	No	300,000	0.137	13,533
BKK Carson (Victoria Golf Course)	<1/1/88	No	>1,000,000	0.457	0
Black Butte SWDS	2002	No	<100,000	0.046	6,359
Boron SLF	2013	No	315,000	0.144	3,238
Borrego Springs LF	2013	No	<100,000	0.046	3,656
Brawley LF	2002	No	200,000	0.091	22,971
Bridgeport SLF	2107	No	<100,000	0.046	<1,000
Burlingham LF	1994	No	2,000,000	0.913	0
Buttonwillow SLF	1998	No	<100,000	0.046	<1,000
Cal Compact/Metro LF	1965	No	4,000,000	1.826	0
Calexico DS	2136	No	<100,000	0.046	1,472
California Valley LF	1997	No	<100,000	0.046	0
Camp Roberts SWDS	2015	No	<100,000	0.046	<1,000
Camp San Luis Obispo	1989	No	<100,000	0.046	0
Casper Refuse DF	1994	Passive Venting	200,000	0.091	0
Cecilville LF	1994	No	<100,000	0.046	0
Cedarville	1993	No	<100,000	0.046	0
Chalfant SLF	2155	No	<100,000	0.046	0
Chester LF	2045	No	100,000	0.046	0
City of Ukiah SWDS	2001	Active-Venting (LFGTE candidate per USEPA)	1,500,000	0.685	42,856
City of Willits DS	1997	Passive Venting	<100,000	0.046	0
Clipper Creek LF	1990	No	<100,000	0.046	0

Clover Flat LF	2020	No	300,000	0.137	48,094
Clovis LF	2029	No	1,000,000	0.457	37,522
Coalinga DS	2034	No	180,000	0.082	19,223
Colfax LF	2002	No	<100,000	0.046	0
Corcoran LF	1988	No	500,000	0.228	0
Crescent City LF	2002	Passive Venting	600,000	0.274	18,493
Desert Center DS	2011	No	150,000	0.068	<1,000
Eagleville	1993	No	<100,000	0.046	0
Earlimart DS	1998	No	<100,000	0.046	<1,000
Eastlake SLF	2027	No	500,000	0.228	46,712
Echo Gold	1998	No	<100,000	0.046	0
Edwards AFB Main LF	2021	No	300,000	0.137	11,039
Evans Rd LF-P1	1995	No	200,000	0.091	0
Exeter DS	2004	No	<100,000	0.046	0
Foothill LF	2054	No (LFGTE candidate per USEPA)	2,000,000	0.913	253,029
Fort Bidwell	1993	No	<100,000	0.046	0
Fort Irwin	2093	No	250,000	0.114	7,512
Forward LF	2006	No	2,200,000	1.005	1,050,305
French Camp LF	2010	No	220,000	0.100	0
Furnace Creek	1996	No	<100,000	0.046	0
Gillespie	<1/1/88	Air Injection	500,000-1,000,000	0.457	0
Glenn County LF	2021	No	340,000	0.155	19,626
Glennville LF	1995	No	<100,000	0.046	0
Gopher Hill LF	2016	No	200,000	0.091	0
Happy Camp SWDS	1996	No	<100,000	0.046	0
Herlong DF	1996	No	<100,000	0.046	<1,000
Holtville DS	2008	No	<100,000	0.046	1,203

Hot Spa C&F	2021	No	<100,000	0.046	<1,000
Hotelling Gulch LF	1994	No	<100,000	0.046	0
Imperial SWS	2028	No	<100,000	0.046	2,333
Independence DS	2038	No	<100,000	0.046	<1,000
Intermountain LF	1993	No	<100,000	0.046	0
John Smith Road SWDS	2017	No (Active-Flare in place not operational)	800,000	0.365	64,510
Jolon Rd LF	2018	No	275,000	0.126	0
Kelly Gulch LF	1994	No	<100,000	0.046	0
Kennedy Meadows DS	2002	No	<100,000	0.046	0
L & D LF	2018	Active-Venting	1,000,000	0.457	169,916
Lake City	1993	No	<100,000	0.046	0
Lake San Antonio South Shore LF	1991	No	<100,000	0.046	0
Landers DS	2008	No	350,000	0.160	53,031
Las Pulgas LF	2184	No	<500,000	0.228	20,667
Lava Beds LF	1995	No	<100,000	0.046	0
Laytonville LF	1997	No	<100,000	0.046	0
Lebec LF	1991	Passive Venting	200,000	0.091	0
Lenwood-Hinkley	1997	No	200,000	0.091	0
Lone Pine DS	2087	No	<100,000	0.046	1,965
Lost Hills SLF	2038	No	500,000	0.228	1,414
Loyalton LF	2032	No	<100,000	0.046	2,896
Lucerne Vlly	1993	No	<100,000	0.046	0
Madeline DF	1997	No	<100,000	0.046	0
Mariposa Co. SLF	2081	No	300,000	0.137	12,603
McCloud	1995	No	<100,000	0.046	0
McCourtney Rd LF	1997	No (LFGTE candidate per USEPA)	1,000,000	0.457	0

Mecca Landfill II	2011	No	100,000	0.046	12,546
Mojave-Rosamond SLF	1997	No	640,000	0.292	7,378
Morongo DS	1996	No	350,000	0.160	0
Neal RD LF	2018	No	850,000	0.388	151,738
Needles Sanitary LF	1994	No	100,000	0.046	0
New Cuyama	1997	No	<100,000	0.046	0
New Tenant SWDS	1995	No	<100,000	0.046	0
Newberry	1991	No	<100,000	0.046	0
Niland C&F	2003	No	<100,000	0.046	<1,000
North County LF	2033	No	1,000,000	0.457	105,029
Oasis DS	2019	No	100,000	0.046	0
Ocotillo C&F	2005	No	<100,000	0.046	<1,000
Old San Marcos	<1/1/88	No	500,000-1,000,000	0.457	0
Oro Grande	1993	No	400,000	0.183	0
Pacific Missile TC LF	1991	No	<100,000	0.046	0
Palo Verde C& F	2029	No	<100,000	0.046	<1,000
Paradise Pk.	<1/1/88	No	500,000-1,000,000	0.457	0
Pebbly Beach	2033	No	<100,000	0.046	1,020
Phelan RDS	2004	No	750,000	0.342	0
Pichacho C&F	2000	No	<100,000	0.046	2,203
Pitchess Detention Cntr	1993	No	<100,000	0.046	0
Ponderosa SLF	1995	No	<100,000	0.046	0
Portola LF	2022	No	<100,000	0.046	1,029
Pumice Valley	2036	No	<100,000	0.046	5,142
Ravendale DF	1997	No	<100,000	0.046	0
Red Hill SLF	1990	No	160,000	0.073	0
Republic-Imperial	2012	No	500,000	0.228	117,405

Ridgecrest SLF	2012	No (LFGTE candidate per USEPA)	2,000,000	0.913	56,377
Rio Vista	1992	No	200,000	0.091	0
Rock Creek LF	2032	No	300,000	0.137	34,450
Rogers Creek LF	1994	No	<100,000	0.046	0
Roseville LF	1980	Passive Venting	500,000-1,000,000	0.457	0
Salton City C&F	2019	No	<100,000	0.046	<1,000
San Mateo Composting (3rd Ave.)	1989	No	600,000	0.274	0
San Onofre LF	2257	No	<100,000	0.046	3,317
Shafter-Wasco SLF	2022	No (Tier 2 NSPS/EG control measures required at 2005) (LFGTE candidate per USEPA)	1,700,000	0.776	120,683
Shoshone DS	2052	No	<100,000	0.046	<1,000
Sierra Army Depot	2032	No	<100,000	0.046	<1,000
South Coast Rd LF	2000	No	<100,000	0.046	1,876
Stonyford LF	2059	No	<100,000	0.046	<1,000
Taft SLF	2041	No	720,000	0.329	27,313
Teapot Dome DS	2005	No (LFGTE candidate per USEPA)	1,000,000	0.457	55,977
Tecopa DS	2050	No	<100,000	0.046	<1,000
Tehachapi SLF	2007	No	390,000	0.178	33,662
Tequesquite/City of Riverside	1985	No	>1,000,000	0.457	0
Trona Angus LF	1996	No	<100,000	0.046	0
Tulelake SWDS	2001	No	<100,000	0.046	<1,000
Tuolumne Central (Jamestown)	1996	No	500,000	0.228	0
Twentynine Palms DS	1997	No	500,000	0.228	0
Two Harbors LF	1995	No	<100,000	0.046	<1,000

US Navy LF (San Clemente Island	2029	No	<100,000	0.046	1,465
USMC- 29 Palms	2002	No	100,000	0.046	3,981
Valley Center	<1/1/88	No	130,000	0.059	0
Vandenburg AFB	2034	No	300,000	0.137	10,258
Ventucopa LF	1997	No	<100,000	0.046	0
Victorville RDS	2005	No	1,300,000	0.594	211,387
Walker SLF	2194	No	<100,000	0.046	<1,000
Weaverville LF	2050	No	100,000	0.046	<1,000
Weed SWDS	1995	No	<100,000	0.046	0
West Central (Phase 2)	2013	No	700,000	0.320	125,527
West Marin SLF	1998	No	<100,000	0.046	0
Westwood DF	1999	No	<100,000	0.046	<1,000
Yermo DS	1999	No	<100,000	0.046	0
Yreka LF	2109	No	<100,000	0.046	8,303
Zanker Rd. LF	2005	No	1,000,000	0.457	16,250